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Title

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Author names and affiliation

Keiichi Uchida[1], Ryuichi Hagita[1], Toshifumi Hayashi[1], Tadashi Tokai[1]*

1 *Tokyo University of Marine Science and Technology, Konan, Minato, Tokyo 108-8477, Japan*

*Corresponding author.

Tadashi Tokai tokai@kaiyodai.ac.jp , Tel +81 3 5463 04743, Fax +81 3 5463 0399,

Keiichi Uchida kuchida@kaiyodai.ac.jp

Ryuichi Hagita hagita@kaiyodai.ac.jp

Toshifumi Hayashi aurora@kaiyodai.ac.jp

Tadashi Tokai tokai@kaiyodai.ac.jp

Abstract

Sampling was conducted at 31 sites in the western Pacific Ocean from 2000 to 2001 with the aim of collecting plastic fragments with a neuston net (mesh size: 1.00 mm × 1.64 mm). Small plastic fragments including microplastics (small fragments in the size range of 1.1–41.8 mm) were collected at multiple survey sites. Waters with high densities of small fragments were observed between 20°N and 30°N to the south of Japan and between 20°S and 30°S to the northeast of New Zealand (maxima of 6.63×10^2 and 2.04×10^2 pieces/ha, respectively). These waters are located to the west of the Ekman convergence zones related to trade winds in the subtropical gyres of the North and South Pacific Oceans. Nearly no small plastics were observed in the tropical circulation of the western Pacific Ocean.

(136 words)

Keywords: Western Pacific Ocean, microplastics, mesoplastics, subtropical gyre, tropical circulation

Small plastic fragments including plastic resin pellets that drift in the ocean have attracted attention since the 1970s due to their ability to adsorb and transport persistent organic pollutants [1, 2]. Previous surveys conducted in Tokyo Bay and Sagami Bay suggested that the plastic resin pellets found in the ocean were originated from the land [3]. Microplastics, which are derived from mismanaged plastic wastes discharged into the ocean and are degraded into small fragments by exposure to ultraviolet radiation and mechanical erosion, have also attracted considerable attention [4]. The amount of these small plastic fragments is particularly high in the East Asian seas, including those around Japan [5]. The environmental risk of these small plastic fragments arises partly from their ingestion by marine organisms; moreover, recent studies have found ingested plastic fragments in a variety of marine organisms [6-8]. Although previous microplastic surveys have been conducted in the five gyres and marginal seas, surveys in the tropical waters of the Pacific Ocean are not yet sufficient [5, 8-10]. In addition, microplastic, which is now regarded as an oceanic pollutant, has not been observed operationally; therefore, the archived dataset of plastic fragments in the world's oceans remains quite poor. Mismanaged plastic wastes discharged into the ocean are likely to increase rapidly over the next decade, especially, in East and Southeast Asian countries [11]. The abundance of ocean-borne microplastics in the past provides us with important information to elucidate to what extent small plastic fragments have increased in the oceans in the past and to what extent these fragments will increase in the future.

Therefore, we present the abundance of small plastic fragments collected using a neuston net in the pelagic zone of the western Pacific from 2000 to 2001 aboard a training vessel belonging to the Tokyo University of Marine Science and Technology (previously, the Tokyo University of Fisheries). The survey areas (Fig. 1) covered a broad area in the western Pacific; therefore, the data will be useful for comparisons with microplastic abundances observed at nearby locations now and in the future.

Materials and Methods

The sampling was performed outside the exclusive economic zones of the surrounding countries during the period from October 2000 to March 2001 by the training vessel, *Umitaka-maru* IV, belonging to the Tokyo University of Marine Science and Technology. Because the primary aim of the survey was to collect small plastic fragments with sizes of a few millimeters including plastic resin pellets, which are regarded as one of the principle plastic polluters, a neuston net with a mouth of 700 mm × 700 mm and a mesh size of 1.00 mm × 1.64 mm was used for the surveys. The buoyancy of the net was adjusted such that the upper half the net mouth was exposed above the sea surface while towing approximately 1 m from the port side hull of the ship. The ship speed during towing was maintained at approximately 2–3 knots during each 10 min tow. The start and finish locations of the transects were determined on the basis of the latitude and longitude coordinates measured using a GPS. Sampling was conducted every two days unless towing was difficult due to stormy weather conditions.

In the laboratory onboard the ship, the small plastic fragments were immediately spotted with the naked eye and separated from natural materials, including zooplankton, based on shapes and colors in a manner similar to Ogi and Fukumoto [1]. The plastic fragments were then counted and photographed using a digital camera. The material composition of the collected plastic fragments was not determined in this study. After the voyage, the length of the longest axis of each fragment was measured from the digital photographs. The fragments were classified according to their shapes, such as granular, sheet-like, string-like, based on the photographs. For this study, the volume of seawater passing through the net could not be calculated because a flow meter was not installed at the mouth of the net. Therefore, the filtered area was estimated on the basis of the width of the net mouth and the towing distance, which was determined using the GPS data. In the procedure used to measure the small plastic fragments, the "distribution density" of the fragments was defined as the number of fragments per unit area with units of pieces/ha (ha = 10^4 m^2).

Results

In total, sampling was conducted at 31 stations: 9 stations between Tokyo and New Caledonia (Stns. 1–9), 2 stations between New Caledonia and New Zealand (Stns. 10 and 11), 6 stations between New Zealand and Tahiti (Stns. 12–17), 12 stations between Tahiti and Hawaii (Stns. 18–29), and 2 stations between Hawaii and Tokyo (Stns. 30–31). The locations of Stn. 20–26 were crowded because they were conducted in conjunction with operations with tuna longline fisheries. Small plastic fragments were collected at 15 of 31 stations (see Fig. 1 and Table 1 for the distribution density at each station). Figure 2 shows photographs of all the fragments collected at each station. Every plastic particle appeared to be a fragment or plastic fiber derived from the breakdown of larger plastic products. No virgin plastic pellets, such as disc- or cylindrical-shaped plastic resin pellets, were found in the collected plastic fragments (Fig. 2). Granular fragments were the most commonly collected, comprising 67% of the total (Fig. 2 and Table 1). The greatest variety of plastic fragment shapes was found at Stn. 1.

The highest distribution density was also found at Stn. 1, closest to Japan (6.63×10^2 pieces/ha). At Stn. 1, a roll of plastic tape was found together with plastic fragments, as shown in Fig. 2 (the red piece in Stn. 1); however, these fragments were excluded from the analysis because they were not categorized as “small plastic fragments,” the objective of the study. The distribution density decreased moving southward from the mid-latitude in the Northern Hemisphere to the equator, and the small plastic fragments disappeared at Stns. 7–9 in the Southern Hemisphere beyond the equator. However, in the Tasman Sea, plastic fragments with a density of 2.24×10^2 pieces/ha were again collected at Stn. 10. Furthermore, between New Zealand and Tahiti, a distribution density of 5.0×10^2 pieces/ha was observed at Stn. 12 northeast of New Zealand. The highest density of small plastics observed in the Southern Hemisphere was 2.03×10^2 pieces/ha, which was recorded at Stn. 14 further northeast of New Zealand. The density was relatively low (6.3×10 pieces/ha) at

Stn. 15. In addition, no small plastic fragments were collected to the north of Stn. 16 in the Southern Hemisphere. At Stn. 25 in the Northern Hemisphere between Tahiti and Hawaii, only burned fragments of a petrochemical material were collected (see Fig. 2). A density of 1.8 × 10 pieces/ha was recorded at Stn. 29 to the south of Hawaii, and the density tended to increase from Hawaii (Stn. 30: 2.9 × 10 pieces/ha) toward Japan (Stn. 31: 1.64×10^2 pieces/ha). As aforementioned, 67% of the fragments collected in this study had a granular shape, and a relatively large amount of granular-shaped fragments was observed over the entire study area (see Table 1).

The sizes of the small plastic fragments were determined by their length along their longest axis, and their size range was from 1.1 to 41.8 mm with an average of 5.7 mm and a median of 3.6 mm (Fig. 3). Approximately 70% of the fragments were categorized as microplastics, defined as plastic fragments with a size smaller than 5 mm [12]. No fragments smaller than 1 mm were collected due to the net mesh size of 1.00 mm × 1.64 mm (Fig. 3). The mean sizes of the fragments collected in the Northern and Southern hemispheres had no significant statistical difference ($t = 0.24$, $p > 0.05$).

Discussion

In this survey, high densities of small plastic fragments (>50 pieces/ha) were observed in the waters from 20° 0' N to 29° 10' N to the south of Japan and from 27° 8' S to 32° 36' S to the northeast of New Zealand. There are surface convergence regions in the subtropical gyres in the North Pacific, South Pacific, North Atlantic, South Atlantic, and Indian oceans [8]. The convergence of floating marine debris in these waters occurs due to a similar mechanism: floating marine debris converge toward a mid-latitude belt by the Ekman flows and then move further eastward by geostrophic currents to form a high-density region [13, 14]. The high densities of plastic fragments observed in both the North and South Pacific oceans were located in the western areas of the subtropical convergence regions in the mid-latitudes [8]. However, floating marine debris in equatorial waters is likely to be continually transported westward in the absence of a convergence zone until the debris reaches to the east of the Philippines and the Indonesian archipelago due to the Equatorial currents (Kubota et al. [14] for the argument for the Northern Hemisphere). In fact, except for the burned fragments collected at Stn. 25, practically, no small plastic fragments were collected over the tropical waters in the presented survey (Stns. 7–9 and 18–28). The burned petrochemical fragments collected at Stn. 25 might have been released from one of the tuna longline fishing vessels operating in the vicinity. Jembeck et al. [11] suggested that some countries in East and Southeast Asia discharge a large amount of mismanaged plastic wastes into the ocean and Isobe et al. [5] demonstrated that the waters around Japan downstream of these countries were a hot spot for pelagic microplastic due to the Kuroshio Current [5]. This suggests that microplastics may flow into the North Pacific from this hot spot.

The mode of the fragment size observed in this study was approximately 3 mm. The abundance of the fragments decreased as they become smaller than the mode size, and no fragments with a size ≤ 1 mm were collected (Fig. 3). As aforementioned, this may have been caused in part by the relatively coarse mesh size of the neuston net (1.00 mm × 1.64 mm). In addition, the usage of a stereomicroscope rather than the naked eye to extract the small plastic fragments might have increased their numbers, especially, in size ranges smaller than 3 mm. Neuston nets with a mesh size of 0.333 mm have been used for microplastic surveys in recent years [5, 15]. In those studies (e.g., Isobe et al. [5] and Isobe et al. [16]), the mode in the longest axis length was in the vicinity of 1 mm, and a large amount of microplastics smaller than 1 mm was also collected. According to Eriksen et al. [9], approximately 40% of the plastic fragments had sizes smaller than 1 mm in their survey conducted in the eastern South Pacific in 2011. Consequently, the distribution densities of microplastics in the presented study were potentially underestimated. Therefore, it is not possible to make an in-depth examination of microplastic behaviors such as their vertical distribution (e.g., Kukulka et al. [17]); this will be explored in a future study.

The presented study provides an overview of the distribution of small plastic fragments in the western

Pacific Ocean from 2000 to 2001. However, future studies will need to employ neuston nets equipped with a flow meter and a finer mesh size, as seen in recent studies. Note that the distribution densities computed in the presented study might not be directly comparable to other microplastic data obtained under different wind/wave conditions. This is because the density of lightweight microplastics drifting in the surface layer rapidly decreases (increases) in the high (low) vertical mixing under stormy (calm) oceanic conditions. Vertically integrating the densities at depth yields the microplastic number for the entire water column; therefore, this value is required for comparisons with other microplastic data collected under other oceanic conditions irrespective of vertical mixing. Such a “vertical correction” should be performed on the fragment abundance obtained in the presented study using archived wave/wind data. Recently, a survey of small plastic fragments in conjunction with the sequential monitoring of wind/waves was conducted by the T/V *Umitaka-maru* along a track from the Antarctic Ocean to Tokyo during the period of February–March 2016. These surveys included sampling in the vicinity of Stns. 1–11 of this study; therefore, we can demonstrate changes in the distribution densities, sizes, and shapes of small plastic fragments over the past 15 years.

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Figure captions

Fig. 1. Sampling locations and the distribution density (see the text for the definition) of small floating plastic fragments at each station (pieces/ha).

Fig. 2. Photographs of the small floating plastic fragments collected at each station.

Fig. 3. Frequency distribution of the longest-axis length of the plastic fragments collected by visual identification. Plastic fragments with a long axis <5 mm accounted for 70% of the collected samples.